Immersive Methods for Mine Warfare

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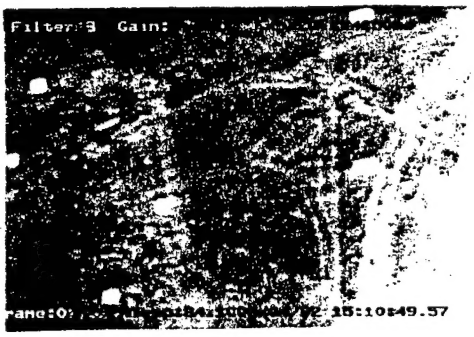

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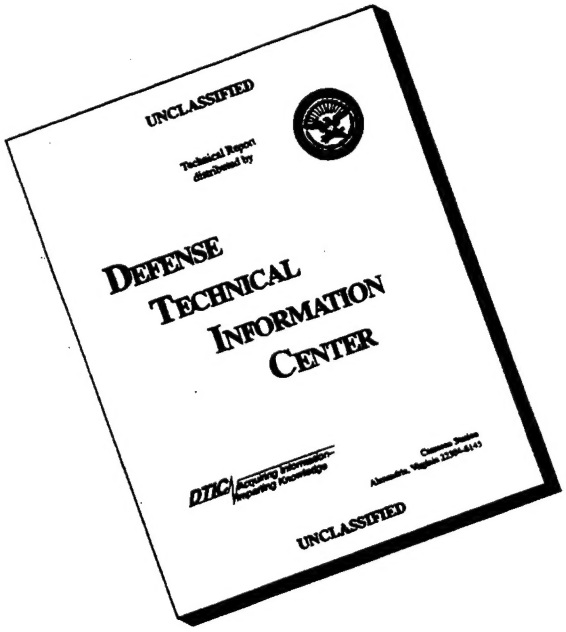

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Immersive Methods for Mine Warfare

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Abstract:

We are developing a synthetic environment to be used in combination with real environments for the purpose of mine counter measures. Two examples of our work involve applications to land-based minefields and an application to submarine defense. In the former application, imaging is done with six spectral bands. It has been shown empirically that a sequence of images taken in six spectral bands when viewed sequentially will allow one to distinguish between real mines, partially buried real mines, decoys, other metallic objects, and other manner of debris. The image can be viewed as a 2-dimensional image with an 6-dimensional vector attached to each pixel location. We use the grand-tour technique (Wegman and Shen, 1993) to find an optimal discrimant between real mines and other objects. We then use a head-mounted display (HMD) which is semitransparent so that the real-world objects can be seen through it. After processing the scene, the suspected sites of real mines are superimposed on the visual field so that the soldier wearing the HMD is alerted to the presence of mines.

The submarine application is similar in that multisensor information is collected for the environment surrounding the submarine. In effect, we have a low-dimensional vector attached to each voxel in the 3-dimensional image surrounding the submarine. Again a grand tour is performed to optimize the multisensor data for detection of hostile objects around the submarine. In this application, a command information center is constructed with 3-dimensional capable projection systems. We create a CAVE-like environment in which each wall is essentially a projection screen for a 3-dimensional image of the corresponding underwater environment synthetically reconstructed based on our multisensor data. We use Crystal Eyes technology and Silicon Graphics Onyx systems in our laboratory.

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1. The Desktop Metaphor, Virtual Reality, and Scientific Visualization

The desktop metaphor is a common conceptualization of a human-computer interface which is instantiated in many current computer operating systems including the MacOS, Windows 3.1 and Windows95, and, in fact, many UNIX-based operating systems such as those of the Silicon Graphics systems. The basic idea is that the computer screen is in effect a virtual desktop, that windows within the computer screen are virtual pieces of paper, and that by using a mouse, the user can manipulate this virtual desktop in a way analogous to a conventional desktop. The computer user, of course, has several great advantages over a conventional paper-and-pencil desktop user since the computer is capable of a much richer response. That is, drawings are far easier to make using a computer, text editing is far easier, dynamic interaction is far easier. The library is literally whatever is accessible on the net. Interestingly enough, constructing and writing mathematics is considerably easier with a conventional desktop, because a substantial extra effort is required for the writing and formatting of mathematical arguments in a computer system.

To a large extent the desktop metaphor is satisfying to a scientist since much of the analysis work that a scientist does is desktop oriented. Thus the translation from a conventional desktop to a computer environment is quite satisfactory. The popularity and prevalence of computing within the scientific community, which is apparent to all, is a strong indication of the success of the desktop metaphor. For the scientific visualization community, there is a second less well recognized and articulated metaphor, what we shall call the "explorer" metaphor. The phrase, exploratory data analysis, now a phrase in common usage, captures the essence of this metaphor. Projection pursuit and high interaction dynamic graphics are additional phrases we use to convey an exploratory sense of proactive involvement with our data. Within the more traditional computer science community, the phrases data mining and knowledge discovery again attempt to capture the exploration of data and databases. It is our assertion that these phrases implicitly represent a different metaphor from that of the desk-bound analyst, and, in some sense, capture this more "explorer" metaphor. It is interesting to note, for example, in a recent paper, Huber (1994) writes of exploratory analysis with a mountain climbing metaphor, the Himalayan metaphor. Fortuitously, the mixing of these metaphors has to some extent been captured in several successful modern windows-oriented graphical data analysis systems, notably such systems as Splus, DataDesk and JMP.

Our thesis is that so-called virtual reality offers a better technology for human-computer interaction as it relates to exploratory analysis than does the desktop metaphor. Virtual reality technology not only offers the possibility of a more visceral engagement of the data world, but also offers a much more compelling visual focus than does a standard computer screen. Regrettably, virtual reality, like artificial intelligence, expert systems, and neural nets, is a subject of much hype and inflated promises, more than are likely to become real in the near term. For the reason, we have routinely chosen phrases like immersive technology, synthetic environments, and augmented reality to describe our

work. We briefly describe our interpretation of the explorer metaphor in terms of virtual reality technology.

Wegman and Carr (1993) described a sea-exploration metaphor for several levels of immersive environments. They described three levels of immersion. The first is what we think of as exploring the undersea environment with a remotely piloted vehicle (RPV). In this mode, an operator typically sits with a joystick controller watching a television monitor, and maneuvers the RPV with the joystick. This is roughly analogous to doing exploratory data analysis with a mouse on a computer screen. The next model is what we have called the aquarium model. This is like studying undersea life in an aquarium with a floor-to-ceiling, wall-to-wall glass wall. The explorer gets a 3-dimensional view without being seriously encumbered with equipment. In our instantiation, we use a three-dimensional, stereoscopic projection system which gives us a 15-foot diagonal image in a stereoscopic, full-color display. We'll discuss more of the technical details later. The final model is what we have referred to as the skin-diver model. The analogy is strapping on the wet suit, the oxygen tanks, and the face mask and diving to explore the undersea environment. The computer analogy is to put on the head-mounted display, the tracker mechanism, and a glove, and engage the computer-generated virtual world directly. As with the skin diver, there are some equipments that must be used, which, truthfully, are somewhat cumbersome and, certainly at first, awkward to use. These three levels of immersion represent three levels of potential exploratory interaction with the data world.

Obviously, the RPV model is well exploited. We have exploited the aquarium model and have generally found our limited explorations to be quite successful. The projection system allows for the high resolution desirable in a graphical analysis and the lack of physical encumbrances allows a focus on data exploration. The skin diver model has been poorly exploited for exploratory analysis to date. The early versions of head mounted displays were either high resolution, but outrageously expensive, say on the order of US$100,000, or affordable, on the order of US$6000 to US$8000, but poor enough in resolution so as to be unusable for statistical data graphics purposes. This situation has recently changed somewhat with the introduction of the Virtual Research VR-4 head-mounted display. This HMD is priced at about US$8000 and has resolution comparable to S-VGA.

Our thesis then is that these immersive technologies offer a data exploration framework that has the potential for a much more direct interaction with the data world. The major thrust of our work is to combine scientific visualization, exploratory data analysis and virtual reality into a new technology for exploring data. We have for several years experimented with 3-D visualization and have many aspects of this tool in hand. Our approach has been to treat mathematical constructs as if they were real entities, i.e. treat two- and three-dimensional graphs of mathematical functions as if they were metallic surfaces, and visualize them in three dimensional space with lighting and rendering models similar to the way we would explore a CAD design. Figure 1 represents a two-dimensional density surface derived from statistical data about an image of a military tank surrounded by foliage and other highly textured picture elements. The methodology for

identifying the target involves image segmentation techniques based on fractal geometry. Figure 2 represents the mass distribution of supergalactic clusters with the three variables being declination, right ascension and red shift. Red shift is a surrogate variable for radial distance. Thus Figure 2 quite literally represents the shape of space at the most highly aggregated level.

Data analysis has seen movement of two-dimensional paper-based graphics in the seventies to the computer-based, three-dimensional color graphics of the eighties. Three-dimensional graphics have been achieved by kinematic displays where motion gives the depth cues and by stereoscopic displays. We have used both red-green stereo and polarized-light stereo to good effect. However, as satisfying as these displays are they clearly represent the paradigm of a scientific investigator looking at a screen, i.e. the RPV model. What we are doing is to leave this scenario and immerse the scientific data analyst into a data world. Allowing the analyst to literally move about in the data world, to fly around the data, to look at different portrayals of the data, to make a turn and, literally, turn into another dimension seamlessly. We would imagine a setting where an analyst can actually grab hold of a data point in this virtual world and see the effect of moving it around. We would imagine a setting in which, as the analyst approached a data point in this virtual data world, the numerical value or other attributes of the data point would come into focus. We are creating a data analysis environment where the scientist could quite literally explore the data much the same way that an oceanographer with scuba gear or a submersible could explore the sea. Figures 3 and 4 are two views of a transparent rendered head based on MRI data. We have implemented a full color, transparent, stereoscopic view of this MRI data of which the present images are two-dimensional, gray-scale renderings. In the full VR view, one can literally see internal organs and, with fully immersive technology such as a HMD, one can literally walk around inside of someone's head. Color anaglyph stereo images of these and other visualization images are available at our URL:

http://www.galaxy.gmu.edu/images/gallery/research_arcade.html.

2. Background on the Mine Warfare Problem

The general framework of our research has been oriented to the visualization of scientific data. From this work, we have had the good fortune to interact with researchers from the (U.S.) Naval Surface Warfare Center in Dahlgren, Virginia, with the NSWC Coastal Systems Center in Panama City, Florida, and with the Army Research Laboratory in Aberdeen, Maryland. Suggestions from researchers at these institutions have inspired us to apply some of our visualization techniques to the mine warfare problem. This paper is a description of the problem and our approach to addressing the problem.

In much of the work on visualization for data analysis, spatial extension is considered only as an abstract representation of a data variable, but not as any real entity. Although we have been interested in representation and visualization of multivariate data, it is clear then there are many circumstances in which it is appropriate to measure variables in a spatial or volumetric setting. Consider, for example, the setting of this paper in which

we take images of a minefield in six spectral bands. This is an example of spatially extended multivariate data. At each pixel location, we have six-dimensional multivariate data corresponding to the intensity levels of light in each of the six spectral channels. A minefield may be two-dimensionally extended (spatially extended) in the case of land mines or in the case of underwater naval mines, three-dimensionally extended (volumetrically extended). An alternate civilian application would be to the visualization and analysis of nuclear magnetic resonance imagery (MRI). Here we are concerned with a truly volumetric setting in which multiple sensors may give us partial information about tumor site targets. Again each voxel has a multidimensional vector attached to it which may have many missing observations. This MRI scenario extends in an obvious way to an electronic warfare (EW) electromagnetic environment as well as to other potential civilian applications.

We describe most specifically the land-mine application. This application is motivated by U.S. Marine Corps interests when landing on a possibly mined beachhead. Mines may be laid proud (on the surface) or partially buried. Such a minefield would generally be difficult to navigate because it is difficult to distinguish among the various objects with the unaided eye. However, by using multiple spectral bands including infrared and possibly ultraviolet, it is possible distinguish among them. For example, while a real mine and a hollow metallic object may look similar to the unaided eye in the usual visible light range, the heat absorption characteristics of the two objects would be different and so allow one to distinguish between the two by accounting for radiances in the infrared band. Similarly, a metallic object and a stone object generally react to ultraviolet radiation quite differently due to fluorescence characteristics and, hence, can be distinguished.

Experiments at the Coastal Systems Center, Panama City, Florida involved the construction of a motion picture camera which interposed a different spectral filter, up to a total of six, for each frame in a film sequence. Figures 5 through 10 represent a sequence of six images of the same minefield from a film taken with different spectral filters ranging from 400 to 800 nm. These images came from a film of a variety of objects (mines, decoys, stone and rocks, man-made bricks and concrete objects, wooden objects and other debris either proud or slightly buried) on soil with no vegetation although other images are taken in a variety of settings including in shallow water, on sand, in grass and low shrubs. When the resulting film is viewed, it is quite clear that the rapid sequencing of frames allows one to clearly distinguish the objects. However, because of the strong contrasts of visual properties from frame to frame (i.e. some objects bright in one frame and very dark in the next), such films are very difficult to watch causing an intense fatigue after only a few minutes.

Essentially, the Panama City, Florida experiments demonstrate that multispectral information allows a human viewer to distinguish objects. Because of the persistence of vision, the eye effectively integrates the multispectral information at each pixel location forming the basis for the ability to distinguish objects. Our approach is to recognize the value of the information contained in the multivariate vector at each pixel location, but

rather than ask the human eye-brain system to process the information, to use mathematical/statistical techniques to process the multivariate vector and present it to the viewer in a more palatable form. The technique we will describe in this paper is called the grand tour which is a visualization technique for multidimensional data that we have used very successfully in a variety of scientific visualization problems.

The basic idea of the grand tour is based on the premise that to thoroughly understand an object, it is useful to look at it from all points of view. Briefly, to understand the structure of a cloud of multivariate points in a high dimensional space, one can simply perform a time-dependent general rotation of the multidimensional coordinate axis system so that the rotation is performed in a continuous (smooth) manner and that all possible orientations of the axes are eventually achieved. The idea was original formulated by Asimov (1985) and Buja and Asimov (1985) for a two-dimensional grand tour, and later by Wegman (1991) for the general d-dimensional grand tour and by Wegman and Shen (1993) for a one-dimensional grand tour. The d-dimensional grand tour can be visualized using the parallel coordinate methodology described in Wegman (1990). While the one-dimensional grand tour may not seem so useful, for imaging applications it emerges as a quite useful technique, since the result of a one-dimensional grand tour can be rendered in grey-scale at each pixel location. Thus one can visually search for an optimal linear combination of the components of the multidimensional vector which, in the case of our application, would give maximum visual distinction of real mines from decoys and debris. Our approach concludes by highlighting mine locations on an augmented reality head-mounted display which we describe in a bit more detail in Section 4. In Section 3, we give the technical details of one of our grand tour techniques.

3. Visualization Using the Grand Tour

The goal then is to combine the information in the multivariate vector attached to each pixel or voxel in such a way as to make the objects of interest visually most apparent. There are several potential approaches. Some simple ones are: 1) to use different channels (i.e. vector components) for each eye to give a pseudo stereo effect and 2) to display each of the channels in rapid sequence so as to create a scintillation effect. (We have already employed this technique in the data analysis setting to good effect.) Both of these techniques, while potentially effective, are unlikely to be usable on a sustained basis because of the eye strain and fatigue they are likely to cause. A more sophisticated approach is the one-dimensional grand tour idea.

To explain the grand tour concept, let us consider a point in d-dimensional space. A simple device for doing this is the grand tour. The grand tour concept is built around the idea of looking at an object from all points of view, or more precisely, in all frames of reference. The original work of Asimov (1985) constructed all possible orientations of two-dimensional planes and, then, viewed the data as being projected into those two-planes. The key element of Asimov's grand tour is to have a continuous, space-filling path through the manifold of two-planes. Wegman (1991) considered a continuous, space-filling path through the manifold of d-planes in order to construct the d-dimensional grand

tour. However, it is not difficult to imagine constructing a continuous, space-filling path through the set of straight lines in d-space. For those who are interested, the mathematics of the one-dimensional grand tour are developed in the side-bar.

We use the one-dimensional grand tour idea at each pixel or voxel location. With this device we can examine a continuous series of orthogonal linear combinations of the data at each pixel. We use the same grand tour at each pixel location so that as we move through the grand tour, we discover an optimal combination of the components of the data vector which maximally discriminated background from mines. It is clear that we need a computationally efficient technique. For this purpose we developed pseudo-grand tour plots. The mathematics of the pseudo grand tour are developed in the side-bar labeled *The One-Dimensional Pseudo Grand Tour.*

The grand tour is aimed at finding a useful combination of the multivariate vector components. In the classical approach to the grand tour, the resulting combination of vector components is viewed through a dynamic display. Wegman (1991) and Wegman and Shen (1993) explain how this can be done in the general d-dimensional setting and the 1-dimensional settings respectively. For the multispectral image setting, we have in mind the following technique. In the above formulation, the j subscript refers to the indexing of the pixels. Notice that the grand tour vector does not depend on the pixel. We do the same grand tour for every pixel. The image undergoing the grand tour is displayed in grey-scale or some appropriate color scale. We allow the grand tour to continue until there is a combination of terms which allows the targets (mines) to be visually represented in a way significantly differently from the background clutter. As indicated earlier, the immersive technology allows us to superimpose the grand-tour derived image on the real scene so that the military forces could navigate through mine field with great confidence.

4. The Equipment Base

The development facilities are housed in the virtual reality laboratory of our research center, the Center for Computational Statistics at George Mason University. The facilities have been under active development for just over 30 months. The computer suite used directly in support of the virtual environments facility includes two Silicon Graphics Onyx RE workstations, a Silicon Graphics Crimson VGXT, a Silicon Graphics Indigo Elan, and a Silicon Graphics Power Series 4D/120/GTX. The total hard drive capacity for the Silicon Graphics machines exceeds 10.8 gigabytes. The virtual reality laboratory contains five head mounted display systems, three by Virtual Research, Inc. and two by VI/O technologies. The position sensing of both head and hand is accomplished with Ascension Technology's Flock-of-Birds Sensors and with a Polhemus system. The conversion from RGB high resolution computer display to NTSC is accomplished with a two channel encoder/decoder. We have also installed a Stereographics high resolution projection system. This device is capable of 1280x1024 resolution and projects an approximately 15 foot (five meter) diagonal image. It is driven by the SGI machines and is capable of stereoscopic projection using Stereographics' Crystal Eyes technology.

We supplement the Silicon Graphics computation with an Intel Paragon A4 concurrent computer with 61 nodes capable of a peak speed of 4.2 gigaflops. These machines are tied into the virtual reality labs and we expect to use these machines as compute engines for our virtual environments research. In addition to the visualization capability just described, we will have a five channel audio subsystem featuring S-VHS and laser disk capability. The virtual reality laboratory also contains three color printers, one a Mitsubishi-Shinko dye sublimation printer, other a Hewlett-Packard 1200C/PS ink jet printer, and most recently a QMS color laser printer.

While the development environment described above features very high end equipment, the implementation we have in mind ultimately would be a compact computer-based head-mounted display capable of what we like to term, augmented reality. The idea is to have a head-mounted display which allows the user the capability to see through the display system to the outside world. The concept then is to process the multispectral image data and use the head-mounted display to superimpose warning icons on the real scene to warn the soldier of a suspected mine. To err on the conservative side is, of course, desirable.

The head-mounted display developed by Virtual I O Corporation is called "i-glasses" has most of the desirable characteristics. (Information on the product is available on URL http://www.vio.com) The i-glasses product does support the augmented reality concept by allowing the user to view the external world. The i-glasses video display is a lcd-based stereoscopic screen of 180,000 pixels. This is comparatively low resolution and not really acceptable for a final military product. The i-glasses support the NTSC television standard. The final military product would be a small lightweight integrated system consisting of a camera system, a computer, and the head-mounted display. The pseudo-grand tour algorithms described above are sufficiently fast that for the 180,000 pixel resolution, a Pentium-based computer is adequate.

5. Current Status

The general work on scientific visualization using virtual reality techniques has been well-developed and has begun to emerge in the technical literature. This work was funded by the U.S. Office of Naval Research. More details can be found in Wegman and Carr (1993) or at URL http://www.galaxy.gmu.edu. That work has drawn the attention of several of the naval laboratories, notably our colleagues at NSWC-DD, Dahlgren, Virginia and NSWC-Coastal Systems Center, Panama City, Florida.

6. ASW Underwater Mine Scenario

Closely related to this land mine is the immersive techniques for underwater mines. The idea is similar except that instead of a two-dimensional image we would have a three-dimensional voxel-based view of our environment. The other significant difference is that

in the underwater scenario, we would not have a multispectral view, but a multisensor view which would tend to be of more uneven resolution and few types of sensors for the underwater setting than spectral bands in the land-based setting. Still, the fundamental idea is that is a multivariate data vector attached to each voxel location which can be optimally visualized by performing a one-dimensional grand tour. Such a technique would allow the visualization of targets and mines.

A rather dramatic implementation could be conceived for this setting. We have demonstrated large-scale stereoscopic visualization using the projection techniques together with the Crystal Eyes technology mentioned in Section 3. The Crystal Eyes technology use an active liquid crystal shutter for each eye; the shutters controlled by a computer generated infrared signal. The stereoscopic projection system is capable of 120 frames per second yielding 60 frames per second for each eye. Left eye/right eye perspectives alternate for a very effective stereoscopic view. One can imagine a command information center (CIC) implementation, say on a submarine where each of the six surfaces of a cubical room has a stereoscopically projected image using the Crystal Eyes technology. The target locations based on the processed multisensor data would be projected on the walls, ceiling, and floor with appropriate stereo depth information so that the commander could figuratively see through the walls of his submarine to the targets outside. Of course, bottom topography could be included either from sonar or elevation databases or both. Texture mapping onto the elevation database could given a pseudo-realistic sense of the position.

We have at this point demonstrated pseudo-realistic texture-mapping onto terrain databases with stereoscopic visualization as described above. This is a highly effective technique. We have also used the Intel Paragon with multiple nodes each independently simulating a different target. This work is still in progress.

7. Conclusions

Our work has demonstrated a combination of virtual reality in the form of immersive techniques and augmented reality coupled with statistical visualization tools are extremely useful techniques for extended the soldiers view of his surroundings. These techniques have arisen out of an interest in more traditional scientific visualization of data, but may be applied effectively to military scenarios. Our work is currently in process, but shows great promise.

Acknowledgments

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is supported by ONR through ILIR funding at NSWC-DD. The photos of the minefield were supplied to us by Dr. Ab Dubey at NSWC-Coastal System Center, Panama City, Florida and were acquired under the Marine Corps Landing Force Technology Program.

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Legends for the Figures

Figure 1. Two-dimensional density surface based on fractal measurements of an image of a camouflaged military tank in shrubbery and grass. The peaks in the image discriminate among the textures. The lighting and rendering models allow for visualizing the fine structure on the density surface.

Figure 2. Iso-contours of a four-dimensional density surface based on three dimensional data. The data are the mass distribution of super-galactic clusters with the three spatial variables being declination, right ascension and red shift. Red shift is a surrogate variable for radial distance.

Figure 3. Profile view of a head in a two-dimensional rendering. This image is based on MRI data which was reconstructed to a full three-dimensional image, then rendered as a full colored stereoscopic image with transparency. The internal anatomical structures are visible including skin, sub-dural lining brain, facial musculature, tongue, brain stem and even the cartilage in the tip of the nose. MRI responds to resonance of water molecules, and, hence, primarily to soft tissue rather than bone tissue.

Figure 4. Frontal view of same head. Here the eyes and ear structures as well as the jaw musculature are clearly visible.

Figures 5 through 10. Sequence of aerial photos of a minefield with other debris. Notice the relative brightness of pixels within the minefield, particularly the series of dots in the left third of the images which are mines. Their brightness relative to other locations is variable. The sequence of images goes from an infrared filter (Figure 5) to an ultraviolet filter (Figure 10). These images have been contrast enhanced for presentation. The native images are substantially lower in contrast.

Mathematics of the Grand Tour

In order to construct the one-dimensional grand tour, let us consider a point, $\underset{\sim}{x} = (x_1, \ldots, x_d)$, in d-dimensional space. This point $\underset{\sim}{x}$ is the multivariate vector attached to each pixel or voxel location. For simplicity of exposition, we have suppressed the subscripts identifying the pixel or voxel location. We wish to visualize points of this form. Indeed, we wish to visualize a collection of such points, say, of size n of the form $\underset{\sim j}{x} = (x_1^j, \ldots, x_d^j)$, $j = 1, 2, \ldots, n$ where n is the total number of pixels or voxels under consideration. We wish to consider $y_{jt} = \underset{\sim t}{a}\,\underset{\sim j}{x}$ where $\underset{\sim t}{a}$ is a time-dependent unit vector, that is, we take $\underset{\sim t}{a} = (a_{1t}, a_{2t}, \ldots, a_{dt})$, $t > 0$ as a vector for which

$$\| \underset{\sim t}{a} \|^2 = \sum_{j=1}^{d} a_{jt}^2 = 1 \text{ for every } t.$$

Moreover, it must be the case that, as t ranges over the positive reals, $\underset{\sim t}{a}$ ranges over all possible unit vectors. We wish to have $\underset{\sim t}{a}$ be a continuous function of t and exhaust all possible unit vectors, that is, all possible orientations of the unit vector. The dot product, $y_{jt} = \underset{\sim t}{a}\,\underset{\sim j}{x}$ yields the projection of the $\underset{\sim j}{x}$ data vector into the one-dimensional manifold spanned by the unit vector $\underset{\sim t}{a}$. According to the traditional view of a grand tour, we plot y_{jt} on a fixed one-dimensional coordinate system for time, t increasing. This is the *movie* view.

The grand tour in two dimensions has the same basic set up as in the one-dimensional case except we also define a second vector

$$\underset{\sim t}{b} = (b_{1t}, b_{2t}, \ldots, b_{dt}), t > 0$$

where $\underset{\sim t}{b}$ is a unit vector such that $\underset{\sim t}{a}\,\underset{\sim t}{b} = 0$ for every t, that is, $\underset{\sim t}{a}$ and $\underset{\sim t}{b}$ are orthonormal. Next let $y_{jt}^1 = \underset{\sim t}{a}\,\underset{\sim j}{x}$ and $y_{jt}^2 = \underset{\sim t}{b}\,\underset{\sim j}{x}$. Here we plot y_{jt}^2 versus y_{jt}^1 in a fixed two-dimensional coordinate system with time, t, increasing. Again, this is the *movie* view.

The One-Dimensional Pseudo Grand Tour

Consider now the d-dimensional data vector $\underset{\sim}{x} = (x_1, \ldots, x_d)$. If d is not even, augment $\underset{\sim}{x}$ by one additional 0, so that $\underset{\sim}{x} = (x_1, \ldots, x_d, 0)$. We may assume without loss of generality that d is even. Define,

$$\underset{\sim t}{a}' = (\sin(\omega_1 t), \cos(\omega_1 t), \ldots, \sin(\omega_{d/2} t), \cos(\omega_{d/2} t)).$$

Then

$$\| \underset{\sim t}{a}' \|^2 = \sum_{j=1}^{d/2} (\sin^2(\omega_j t) + \cos^2(\omega_j t)) = d/2.$$

Hence, we rescale by $\sqrt{2/d}$, let $\underset{\sim t}{a} = \sqrt{2/d}\, \underset{\sim t}{a}'$ which implies $\| \underset{\sim t}{a} \| = 1$. For technical reasons, ω_i and ω_j are chosen so that the ratio ω_i/ω_j is irrational for every pair (i,j) and, moreover, no ω_i/ω_j is a rational multiple of any other ω_k/ω_m, $i \neq k$ and $j \neq m$. We know that

$$\cos(\omega_j t) = \pm \sqrt{1 - \sin^2(\omega_j t)}$$

so the scaled vector, $\underset{\sim t}{a}'$, will not exhaust all possible orientations and, hence, will yield only a pseudo-grand tour.

This same idea can be extended to two dimensions in order to construct a pseudo grand tour in two-dimensions. Let

$$\underset{\sim t}{b}' = (\cos(\omega_1 t), -\sin(\omega_1 t), \ldots, \cos(\omega_{d/2} t), -\sin(\omega_{d/2} t)).$$

As before

$$\| \underset{\sim t}{b}' \|^2 = \sum_{j=1}^{d/2} (\cos^2(\omega_j t) + \sin^2(\omega_j t)) = d/2.$$

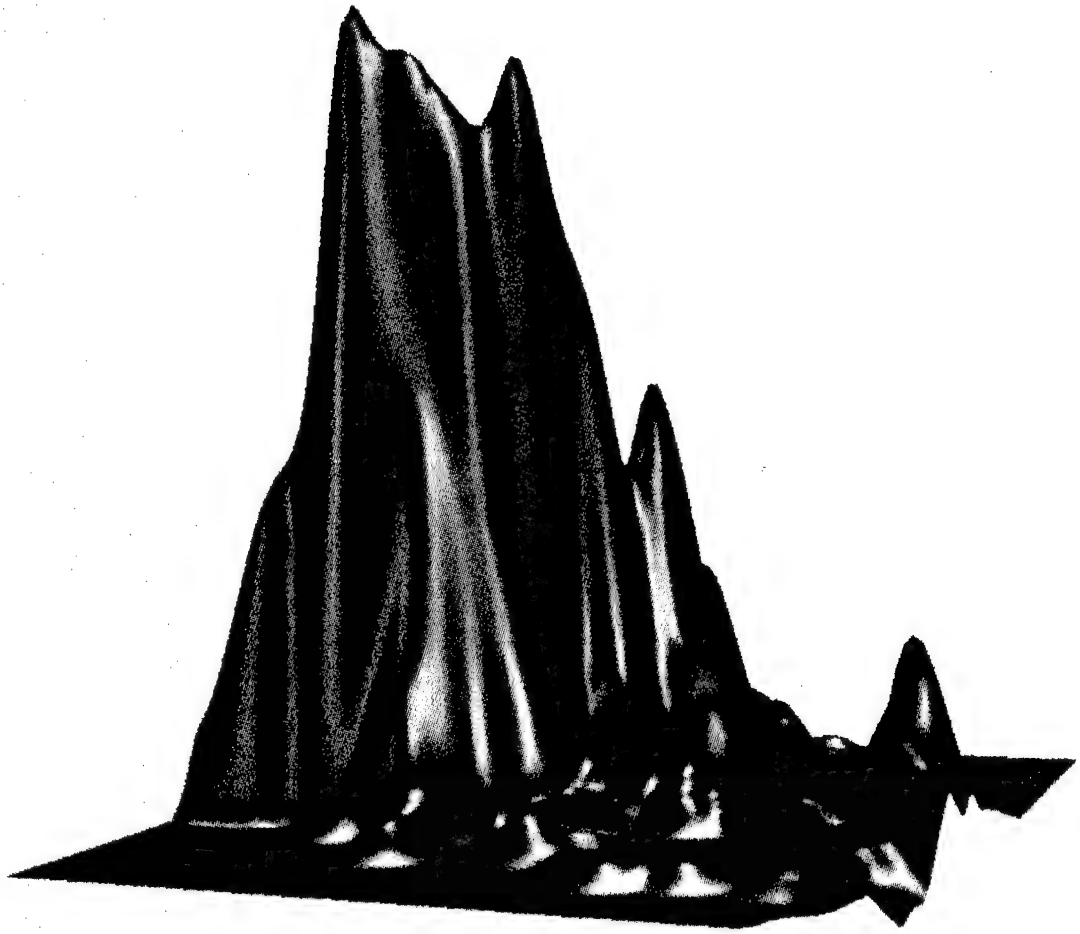
Hence we let

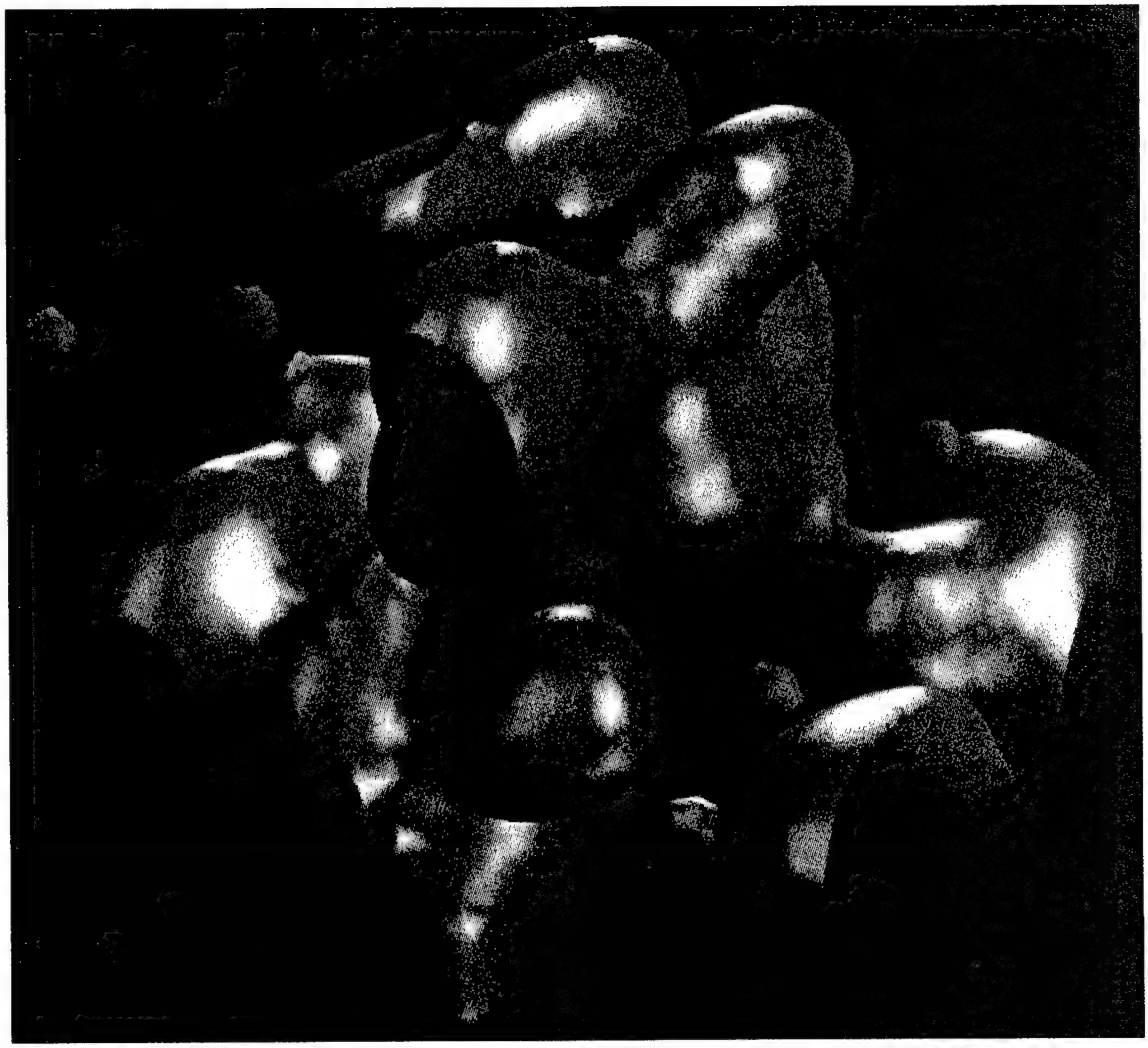
$$\underset{\sim t}{b} = \sqrt{2/d}\, \underset{\sim t}{b}' \text{ which implies } \| \underset{\sim t}{b} \| = 1.$$

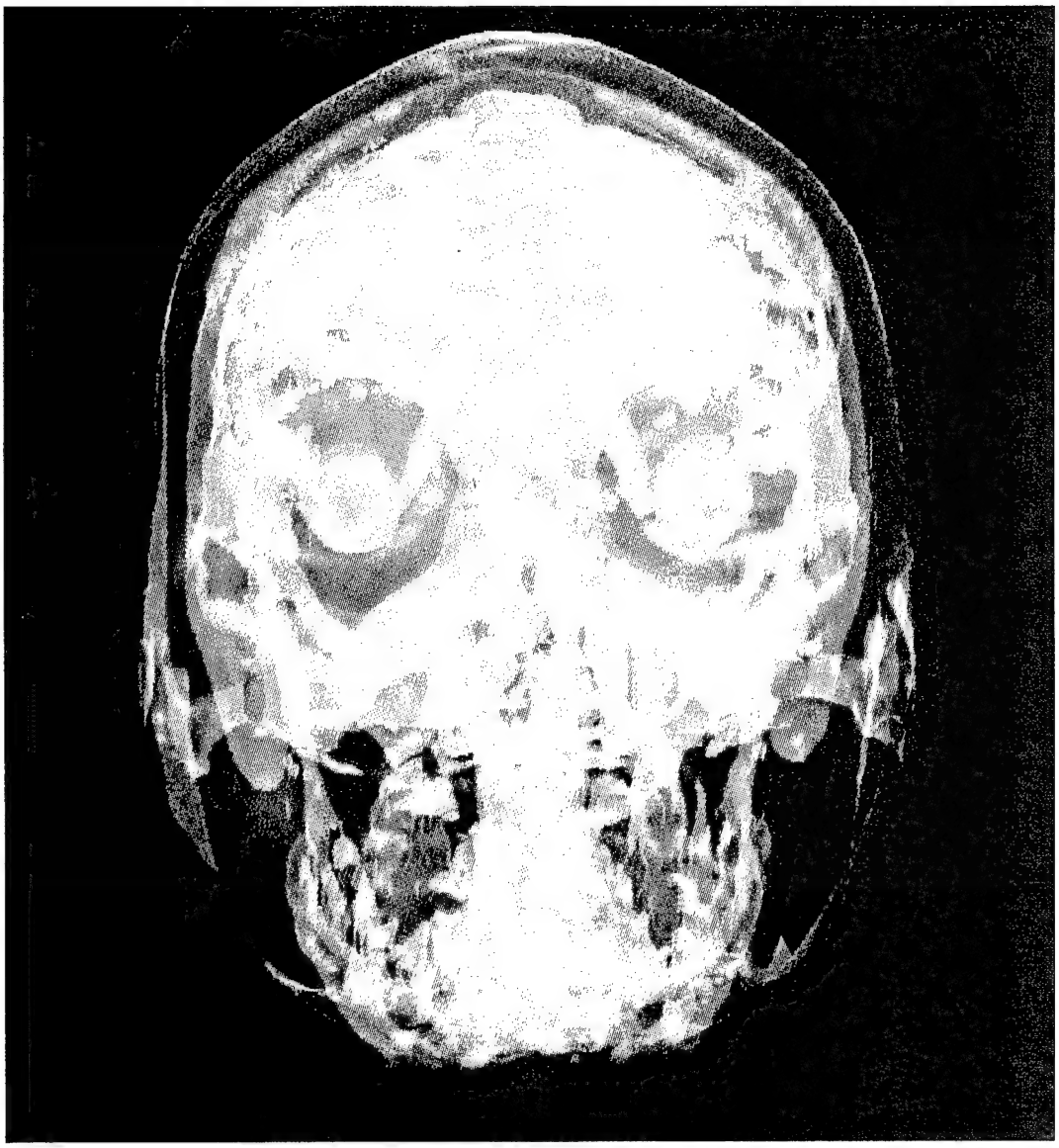
Moreover, by this construction, we have

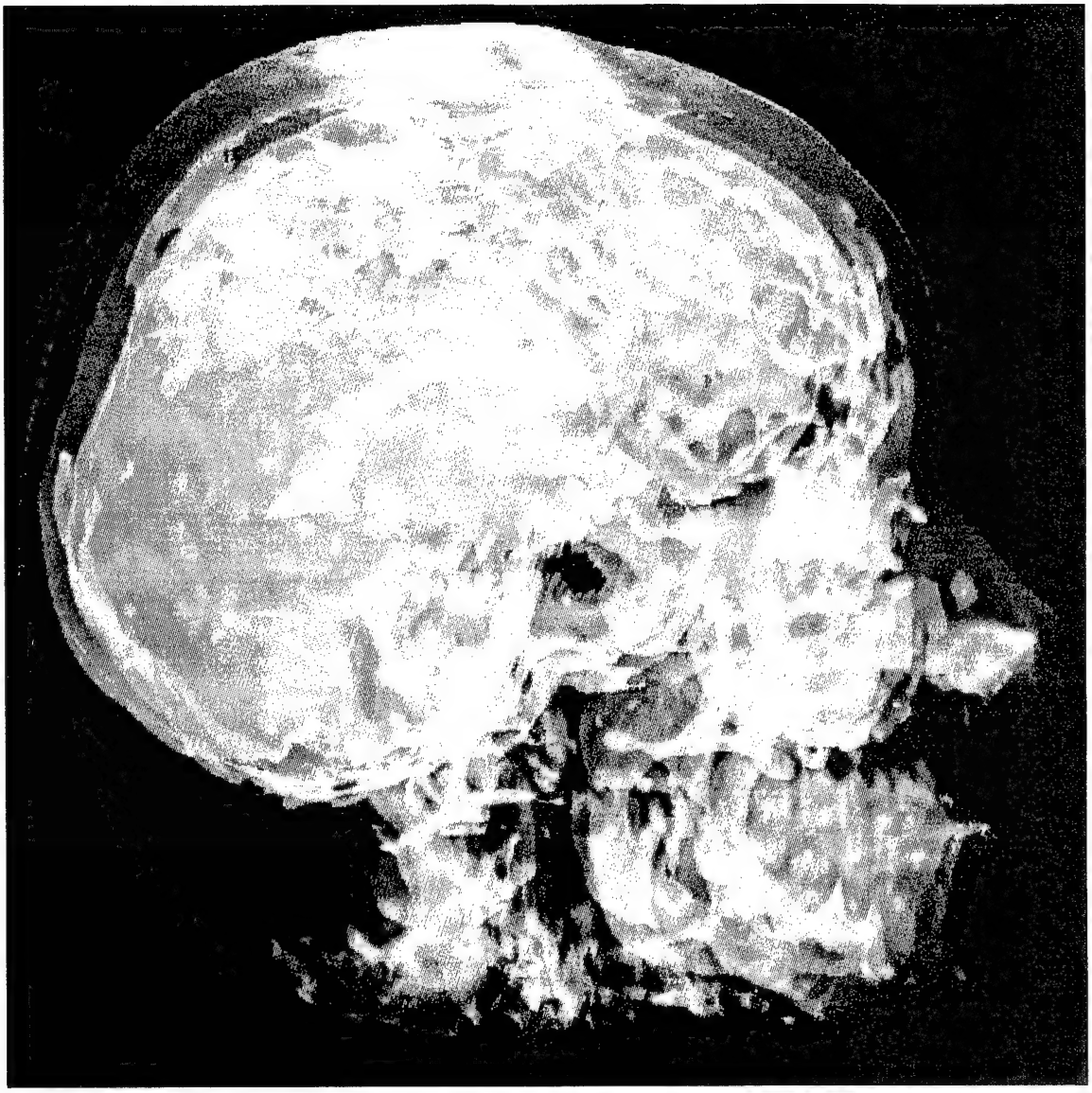
$$\underset{\sim t}{a}\, \underset{\sim t}{b} = \sum_{j=1}^{d/2} \frac{2}{d} (\sin(\omega_j t) \cos(\omega_j t) - \sin(\omega_j t) \cos(\omega_j t)) = 0.$$

Thus $\underset{\sim t}{a}$ and $\underset{\sim t}{b}$ are orthonormal vectors for every $t > 0$. Let $y_{jt}^1 = \underset{\sim t}{a}\, \underset{\sim j}{x}$ and $y_{jt}^2 = \underset{\sim t}{b}\, \underset{\sim j}{x}$. Plotting y_{jt}^2 versus y_{jt}^1 for every j as t ranges over positive reals yields the two-dimensional pseudo-grand tour.









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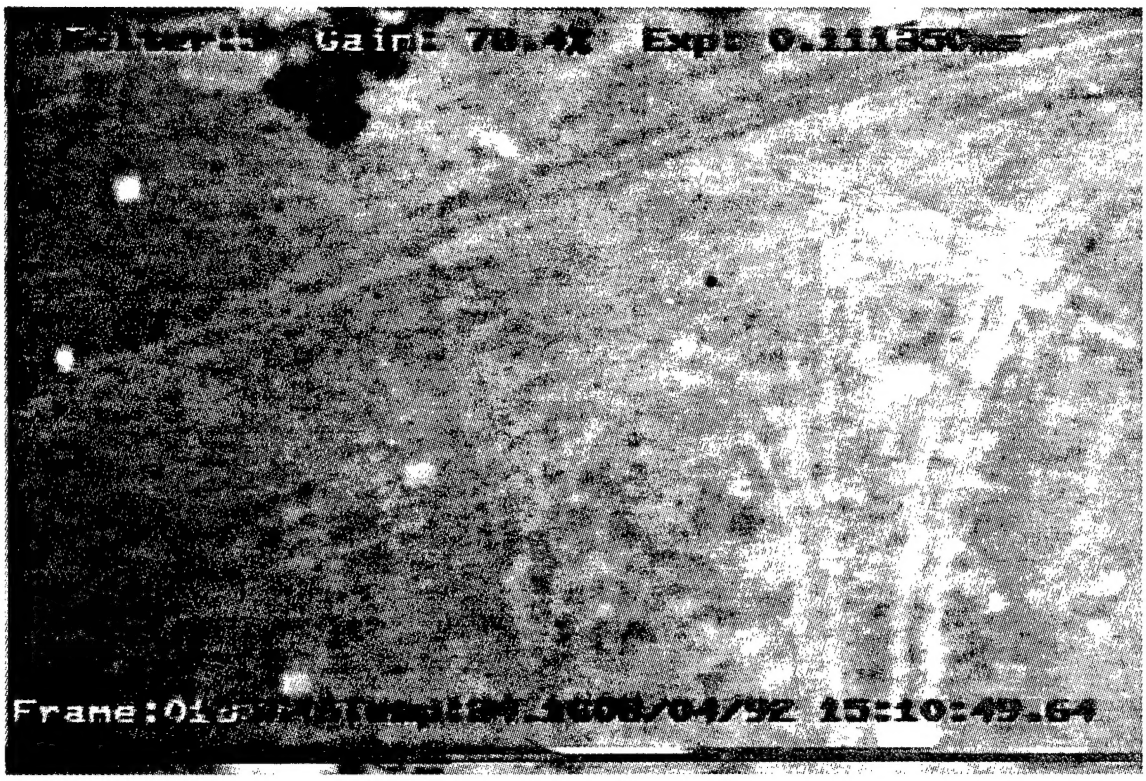
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We are developing a synthetic environment to be used in combination with real environments for the purpose of mine counter measures. Two examples of our work involve applications to land-based minefields and application to submarine defense. In the former application, imaging is done with six spectral bands. It has been shown empirically that seqyence of images taken in six spectral bands when viewed sequentially will allow one to distinguish between real mines, partially buried real mines, decoys, other metallic objects, and other manner of debris. The image can be viewed as a 2-dimensional image with a 6-dimensional vector attached to each pixel location. We use the grand-tour technique (Wegman and Shen, 1993) to find an optimal discrimant between real mines and other objects. We then use a head-mounted display (HMD) which is semitransparent so that the real-world objects can be seen through it. After processing the scene, the suspected sites of real mines are superimposed on the visual field so that the soldier wearing the HMD is alerted to the presence of mines.

The submarine application is similar in that multisensor information is collected for the environment surrounding the submarine. In effect, we have a low-dimensional vector attached to each voxel in the 3-dimensional image surrounding the submarine. Again, a grand tour is performed to optimize the multisensor data for detection of hostile objects around the submarine. In this application, a command information center is constructed with 3-dimensional capable projection systems.

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